COMPACT OPTICAL EQUALIZER

1. Field of the Invention

[0001] The invention relates to one or more optical networking components. In particular, the invention relates to optical equalizers.

2. Background of the Invention

[0002] Optical networks employ a variety of optical components such as optical equalizers. An equalizer is configured to operate on a beam of light signals. Each light signal is associated with different wavelengths. Different light signals often have different intensities. The equalizer provides each of the light signals with the same intensity.

[0003] A typical equalizer includes a demultiplexer for separating light signals of different wavelengths and a beam combiner for re-combining the light signals. A plurality of waveguides connect the demultiplexer and the beam combiner. Each waveguide carries a light signals of a different wavelength. Each waveguide includes an optical attenuator for attenuating the light signals traveling along a waveguide. Because each waveguide carries a light signals of a different wavelength, each attenuator is configured to attenuate the intensity of a different light signal.

[0004] During operation of the equalizer, a light beam having a plurality of light signals passes through the demultiplexer. The demultiplexer separates the beam into different light signals that are each carried by a waveguide. The attenuators are operated so as to attenuate the intensity the light signals such that each light signals has about the same intensity. The beam combiner re-combines the light signals into a beam. Each of the light signals in the beam has about the same intensity.

[0005] The demultiplexer and the beam combiner can each include two star couplers. As a result, the equalizer can include a total of four star couplers. Star couplers are often large and occupy a large portion of the space available on an optical chip. Additionally, the use of four connected star couplers is associated with high levels of optical loss. As a result, there is a need for an equalizer having a reduced size and/or reduced optical loss.

SUMMARY OF THE INVENTION

[0006] The invention relates to an equalizer. The equalizer includes a light distributor configured to distribute light signals received through an inlet side across an outlet side. Each of the light signals is associated with a different wavelength. The equalizer also includes optics configured to cause different light signals to separate as the light signals travel through the light distributor. The equalizer also includes a plurality of attenuators configured to attenuate the light signals in a region of the light distributor where the light signals are separated from one another.

[0007] Another embodiment of the equalizer includes optics configured to separate a beam of light into light signals of different wavelengths. The equalizer includes a plurality of attenuators configured to attenuate the light signals after separation of the light signals. At least one of the attenuators is configured to attenuate a plurality of the light signals.

[0008] The invention also relates to a method of operating an equalizer. The method includes separating a light beam into a plurality of light signals of different wavelengths. The method also includes employing a plurality of attenuators so as to attenuate the intensity of the light signals. At least one of the attenuators is employed so as to attenuate a plurality of the light signals.

BRIEF DESCRIPTION OF THE FIGURES

[0009] Figure 1A illustrates an equalizer having a functional distributor configured to separate light signals according to wavelength.

[0010] Figure 1B illustrates the path of a plurality of light signals through a functional light distributor.

[0011] Figure 1C illustrates a functional light distributor having a plurality of attenuators that are each configured to attenuate a single light signal traveling through the functional light distributor.

[0012] Figure 1D illustrates a functional light distributor having a plurality of attenuators that are each configured to attenuate a plurality of light signals traveling through the functional light distributor.

[0013] Figure 2A illustrates the intensity versus wavelength profile of a plurality of light signals before attenuation by attenuators configured to attenuate a single light signal.

[0014] Figure 2B illustrates the intensity versus wavelength profile for the light signals of Figure 2A after attenuation.

[0015] Figure 2C illustrates the intensity versus wavelength profile of a plurality of light signals before attenuation by attenuators configured to attenuate a plurality of light signals.

[0016] Figure 2D illustrates the intensity versus wavelength profile for the light signals of Figure 2C after attenuation.

[0017] Figure 3A is a top view of an optical component having an equalizer with a functional light distributor. The optical component includes a light transmitting medium positioned on a base.

[0018] Figure 3B is a cross section of the optical component shown in Figure 3A taken at any of the lines labeled A.

[0019] Figure 3C is a cross section of the optical component shown in Figure 3A taken at any of the lines labeled B.

[0020] Figure 3D is a top view of an optical component having an equalizer with a functional light distributor. The functional light distributor includes grooves formed between adjacent attenuators.

[0021] Figure 3E is a cross section of the component shown in Figure 3D taken at the line labeled A.

[0022] Figure 4A through Figure 4F illustrate construction of an attenuator that is suitable for use with functional light distributors constructed according to Figure 3A through Figure 3D.

[0023] Figure 5A through Figure 5D illustrate construction of another attenuator that is suitable for use with functional light distributors constructed according to Figure 3A through Figure 3D.

[0024] Figure 6A through Figure 6F illustrate suitable constructions of bases that are suitable for use with optical components constructed according to Figure 3A through Figure 3F.

[0025] Figure 7A through Figure 7E illustrate a method of forming an optical component having a light transmitting medium positioned on a base.

DETAILED DESCRIPTION

[0026] The invention relates to en equalizer. The equalizer includes a functional light distributor having a plurality of inlet ports and a plurality of outlet port. Light signals entering the light distributor through the inlet ports travel through the light distributor and are distributed across the outlet ports. As the light signals travel through the functional light distributor, the light signals are separated according to wavelength.

[0027] A plurality of attenuators are positioned so as to attenuate the light signals as the light signals travel through the light distributor. In some instances, the attenuators are each positioned so as to attenuate the light signals in the region of the light distributor where the light signals are separated from one another. As a result, each attenuator attenuates a particular light signal as the light signal travels through the light distributor. The attenuators can be operated to attenuate each light signal to about the same intensity level. As a result, the equalizer can provide a beam of light signals that each have about the same intensity.

[0028] As described above, the light distributor separates the light signals, attenuates the light signals and re-combines the light signals. In prior equalizers, these functions were provided by a combination of optical components that included

a plurality of star couplers connected by a plurality of waveguides. Because, these functions are performed by a single component, the current equalizer is more compact than prior equalizers and is associated with reduced optical loss.

[0029] In one embodiment of the equalizer, one or more of the attenuators is configured to attenuate a plurality of the light signals. As a result, the equalizer employs a reduced number of attenuators. Reducing the number of attenuators reduces the complexity and costs associated with the fabricating and operating the equalizer.

[0030] Figure 1A is a schematic diagram of an equalizer 10. The equalizer 10 includes an input light distributor 12 in optical communication with an input waveguide 14. A first array waveguide grating 16 provides optical communication between the input light distributor 12 and a functional light distributor 18. A second array waveguide grating 20 provides optical communication between the functional light distributor 18 and an output light distributor 22. The output light distributor 22 is in optical communication with an output waveguide 24. Suitable input light distributors 12 and/or a suitable output light distributors 22 include, but are not limited to, star couplers, Rowland circles, slab waveguides, free space and multi-mode devices. Suitable functional light distributors 18 include, but are not limited to, slab waveguides, free space and multi-mode devices, cascaded or tandem Rowland circles.

[0031] The first array waveguide grating 16 includes a plurality of first array waveguides 26 and the second array waveguide grating includes a plurality of second array waveguides 28. The first array waveguides 26 each have a different length. The difference in the length of adjacent first array waveguides 26,$\Delta L1$, is a constant. The second array waveguides 28 also have a different length. The difference in the length of adjacent second array waveguides 28, $\Delta L2$, is also a constant. The value of $\Delta L2$ can be the same as $\Delta L1$ or different from $\Delta L2$.

[0032] The functional region includes an inlet side 30 including a plurality of inlet ports 32 and an outlet side 34 including a plurality of outlet ports 36. Suitable shapes for the inlet side 30 and/or the outlet side 34 include, but are not limited to, the shape of a star coupler and a Rowland circle. In some instances, Equation 1

can be used to approximate suitable dimensions of the functional light distributor 18 where d_1 is the grating pitch at the inlet side 30, d_2 is the grating pitch at the outlet side 34, R_1 is the radius of curvature of the inlet side 30, and R_2 is the radius of curvature of the inlet side 34. The maximum distance between the inlet side and the outlet side is $R_1 + R_2$. As a result, the values of $R_1 + R_2$ can be selected to achieve a functional light distributor having particular dimensions or to shift the location of the focal points toward the inlet side or toward the outlet side.

[0033] $$\frac{d_1}{R_1 \Delta L_1} = \frac{d_2}{R_2 \Delta L_2}$$.!

[0034] The dashed line illustrated in Figure 1A shows the path that a light signal travels through the equalizer 10. The lines labeled A show the path of the central ray of the light signal through the functional light distributor 18. The light signal enters the input light distributor 12 from the input waveguide 14. The input light distributor 12 distributes the light signal to a plurality of the array waveguides. The light signal travels through the first array waveguide grating 16 and enters the functional light distributor 18 through the inlet ports 32. The shape of the inlet side 30 causes the light signal to contract to a focal point 40 located between the inlet side 30 and the outlet side 34. The distance between the inlet side 30 and the outlet side 34 allows the light signal to expand such that the light signals is distributed across the outlet ports 36. The second array waveguides 28 carry the light signal to the output light distributor 22. The output light distributor 22 contracts the light signals onto the output waveguide 24.

[0035] Although operation of the equalizer 10 is described above in the context of a single light signal, the equalizer 10 is generally employed in conjunction with a beam of light having a plurality of light signals having a range from about 1529 nm to 1562 nm (C-band), L-band, S-band or other bands. The first array waveguide grating 16 serves as separation optics that cause different light signals to travel through the functional light distributor 18 along different paths. Because the difference in the length of adjacent first array waveguides 26, $\Delta L1$, is a constant, portions of a light signal entering the functional light distributor 18 from different first array waveguides 26 enter the functional light distributor 18 in different phases. Additionally, the amount of this phase differential is different for different light signals

because the value of ΔL1 is a different fraction of the wavelength for different light signals. As a result, different light signals contract to different locations in the functional light distributor 18. For instance, Figure 1B illustrates the path that three light signals travel through a functional light distributor 18. The location of the focal point 40 is different for different light signals. The region of the functional light distributor 18 where the light signals are separated from one another is the separation region 42 of the functional light distributor 18.

[0036] As evident in Figure 1B, different light signals diverge as they travel across the functional region. The portion of the outlet side 34 having outlet ports 36 can be larger than the portion of inlet side 30 having inlet ports 32 to compensate for the divergence of the light signals and/or to provide sufficient power collection. The grating pitch of the inlet ports 32 can be the same as or different from the grating pitch of the outlet ports 36. When the portion of the outlet side 34 having outlet ports 36 is larger than the inlet side 30 and the grating pith of the inlets ports matches the grating pitch of the outlet ports 36, the number of outlet ports 36 in the outlet side 34 will exceed the number of inlet ports 32 in the inlet side 30. As a result, in some instances, the number of second array waveguides 28 exceeds the number of first array waveguides 26.

[0037] After traveling through the separation region 42, the separated light signals re-combine and are incident on the outlet side 34. Because of the difference in the length of adjacent first array waveguides 26, ΔL1, the portions of each light signal entering different outlet ports 36 are out of phase with one another. The second array waveguide grating 20 is configured to compensate for this phase differential. More specifically, the difference in the length of adjacent second array waveguides 28, ΔL2, is selected such that the portions of each light signal entering the output light distributor 22 from different second array waveguides 28 are in phase with one another. Because the portions of each light signal enter the output light distributor 22 in phase, each light signal is directed toward the output waveguide 24. As a result, the output waveguide 24 carries a beam of light having each of the light signals present in the input waveguide 14. A suitable value for the length of adjacent second array waveguides 28, ΔL2, is the value of the length of adjacent first array waveguides 26, ΔL1.

[0038] The equalizer 10 includes a plurality of attenuators 44 in communication with electronics for controlling the equalizer 10. The attenuators 44 are positioned so as to attenuate the light signals as the light signals pass through the separation region 42. For instance, Figure 1C illustrates the path of the central ray of five different light signals. Each attenuator 44 can has a size and position that allows the attenuator 44 to attenuate a particular light signal as the light signal passes through the separation region 42. As a result, the electronics can be operated so as to control the degree of attenuation the will occur to each light signal.

[0039] As an alternative to independent attenuation of each light signal, one or more of the attenuators 44 can be sized and positioned so as to concurrently attenuate a plurality of light signals as illustrated in Figure 1D. Although the one or more attenuators 44 configured to attenuate a plurality of light signals can be configured to attenuate light signals as they pass through the separation region 42, all or a portion of these attenuators 44 can also be configured to attenuate light signals outside of the separation region 42. When one or more attenuators 44 are configured to attenuate a plurality of light signals, a reduced number of attenuators 44 are required. Reducing the number of attenuators 44 reduces the complexity and costs associated with the equalizer 10.

[0040] When each attenuator 44 is configured to attenuate a single light signal, the electronics can be operated so as to attenuate the intensity of each light signal to a target intensity. For instance, Figure 2A illustrates the intensity of the light signals in the input before being attenuated while Figure 2B illustrates the intensity of the light signals after being attenuated. The attenuators 44 are operated so as to attenuate the light signals to the target intensity. As a result, the light signals carried in the output waveguide 24 have about the same intensity. In some instances, the target intensity is the intensity of the light signal having the lowest intensity before attenuation. Alternatively, the target intensity can be less than the intensity of the light signal having the lowest intensity before attenuation. Although Figure 2A and Figure 2B illustrate the light signals attenuated to the same target intensity, the electronics can be operated so different light signals are attenuated to different intensities.

[0041] When one or more attenuators 44 is configured a plurality of light signals, the electronics can be operated so as to attenuate each group of light signals to about the same intensity. For instance, Figure 2C illustrates the intensity of light signals before being attenuated while Figure 2D illustrates the intensity of the light signals after being attenuated. The lines labeled A denote groups of light signals. For instance, the light signals located between two lines labeled A belong to a group of light signals. The light signals in a group can be attenuated by a single attenuator 44.

[0042] The light signals in each group can be attenuated to a target level. In some instances, the target intensity is the average intensity of the group having the lowest average intensity before attenuation. For instance, the lines labeled B in Figure 2C illustrates the average intensity for each group. The group having the lowest average intensity is labeled C. The average intensity of the group labeled C serves as the target intensity. As shown in Figure 2D, the groups are attenuated such that the average intensity of each group is about the target intensity. Other target intensities are suitable for use with the equalizer 10. When the attenuators 44 are configured to attenuate more than one light signal, each of the light signals do not have the same intensity after attenuation as is evident in Figure 2D. However, when an optical network includes more than one equalizer 10 and the grouping of light signals to be attenuated is different for different equalizers 10, the equalizers 10 will average out the intensity of different light signals to about the same intensity.

[0043] In some instances, the grouping of the light signals can be experimentally determined. For instance, light signals that are adjacent to one another in the separation region 42 and having similar intensities can be included in the same group. In this arrangement, each of the light signals is attenuated to about the same intensity. Other methods for assigning light signal groups can be employed. For instance, the attenuators 44 can be arranged such that each attenuator 44 is configured to attenuate a particular number of light signals. Suitable numbers of light signals to be attenuated by a single attenuator 44 include, but are not limited to, 1, 2 or more, 4 or more and 8 or more and different combinations. In some instance, the equalizer is in optical communication with an optical amplifier. The gain of an optical amplifier is typically not flat over the response of the amplifier. As

a result, different levels of gain are applied to different light signals. The attenuators can be arranged such that light signals that are adjacent to one another in the separation region and having similar gain levels fall in the same group.

[0044] Figure 3A through Figure 3C illustrates a suitable construction of an optical component 50 having an equalizer 10. Figure 3A is a top view of a portion of an optical component 50 having an equalizer 10. The illustrated portion of the optical component 50 includes an input waveguide 14, an input light distributor 12, a first array waveguide grating 16 and a functional light distributor 18. Figure 3B is a cross section of the optical component 50 in Figure 3B taken at any of the lines labeled A. Figure 3C is a cross section of the optical component 50 in Figure 3B taken at any of the lines labeled B.

[0045] The optical component 50 includes a light transmitting medium 52 positioned over a base 54. The light transmitting medium 52 includes a ridge 56 that defines a portion of the light signal carrying region 58 of a waveguide. Suitable light transmitting media include, but are not limited to, silicon, polymers and silica, GaAs, InP, SiN, SiC, SiGe, $LiNbO_3$.

[0046] The base 54 is designed such that the portion of the base 54 adjacent to the light signal carrying region 58 reflects light signals from the light signal carrying region 58 back into the light signal carrying region 58. As a result, the base also defines a portion of the light signal carrying region 58. The line labeled E illustrates the profile of a light signal carried in the light signal carrying region 58 of Figure 3B.

[0047] The functional light distributor 18 can include grooves 59 positioned between adjacent attenuators 44 as illustrated in Figure 3D and Figure 3E. Figure 3D is a top view of a portion of the functional light distributor 18 having two attenuators 44. Figure 3E is a cross section of the functional light distributor 18 shown in Figure 3D taken at the line labeled A. The dashed lines show the path of light signals through the functional light distributor 18.

[0048] The grooves 59 can be positioned adjacent to the attenuators 44. For instance, a groove 59 can be formed between adjacent attenuators 44 and/or between an attenuator 44 and a side of the functional light distributor 18. The

grooves 18 can be positioned outside of the light signal paths to reduce undesired reflection of the light signals. As will be discussed in more detail below, a variety of attenuator 44 constructions are possible. The grooves 59 can serve to reduce the effects of one attenuator 44 on the performance of adjacent attenuators 44 or on adjacent light signals. Further, the grooves 59 can reduce the cross talk between adjacent light signals.

[0049] Although the grooves 59 are shown as extending through the light transmitting medium 52, the grooves can extend part way into the light transmitting medium 52 or can extend into the base 54.

[0050] Figure 4A and Figure 4B illustrate an attenuator 44 that is suitable for use with an equalizer 10 constructed as shown in Figure 3A through Figure 3C. Figure 4A is a top view of a portion of a functional light distributor 18 having a plurality of attenuators 44. Figure 4B is a cross section of the functional light distributor 18 shown in Figure 4A.

[0051] The attenuator 44 includes a first electrical contact 60A and a second electrical contact 60B positioned over the ridge 56 of the functional light distributor 18. Suitable metals for the electrical contacts 60 include, but are not limited to, Ni, Cr, Ti, Tungsten, Au, Ct, Pt, Al and/or their silicides. The electrical contacts 60 can be formed to a thickness greater than .1 μm, .5 μm, 1 μm, 1.5 μm or 2 μm or to a thickness less than 4 μm. Electrical conductors such as wires can optionally be connected to the electrical contacts 60 to provide electrical communication between the electronics and the electrical contacts 60.

[0052] A doped region 64 is formed adjacent to each of the electrical contacts 60. The doped regions 64 can be N-type material or P-type material. When one doped region 64 is an N-type material, the other doped region 64 is a P-type material. For instance, the doped region 64 adjacent to the first electrical contact 60A can be a P type material while the material adjacent to the second electrical contact 60B can be an N type material. In some instances, the doped regions 64 of N type material and/or P type material are formed to a concentration of 10^(17-21) /cm^3 at a thickness of less than 6 μm, 4 μm, 2 μm, 1 μm or .5 μm.

[0053] Figure 4A and Figure 4B illustrate operation of the attenuator 44. During operation of the attenuator 44, a potential is applied between the electrical contacts 60. The potential causes the index of refraction of the first light transmitting medium 52 positioned between the electrical contacts 60 to change as shown by the lines labeled A in Figure 4B. When the potential on the electrical contact adjacent to the P-type material is less than the potential element on the electrical contact adjacent to the N-type material, a current flows through the light transmitting medium 52 and the index of refraction decreases.

[0054] The line labeled A in Figure 4A illustrates a light signal traveling toward the attenuator 44. When the attenuator 44 is operated so as to reduce the index of refraction of the light signal carrying region 58, the drop in the index of refraction causes at least a portion of the light signals to be reflected out of the light signal carrying region 58 as illustrated by the lines labeled B. Because a portion of the light signals is reflected out of the light signal carrying region 58, the portion of the light signal exiting the attenuator 44 has a reduced intensity as illustrated by the arrow labeled C. In some instances, when the refractive index drops, optical absorption caused by carrier injection/depletion can occur at the same time. For example, when the light transmitting medium is silicon an efficient method of reducing the index of refraction is by carrier injection from the PN junction.

[0055] Increasing the potential applied between the electrical contacts 60 increases drop in the index of refraction. The increased drop increases the portion of the light signal that is reflected by the attenuator 44. As a result, the increased potential increases the level of attenuation.

[0056] The electrical contacts 60 can be positioned in other orientations relative to the direction of propagation of the light signals through the functional light distributor 18. For instance, Figure 4C illustrates the electrical contacts 60 turned ninety degrees from the electrical contacts 60 of Figure 4A. The arrangement of electrical contacts 60 illustrated in Figure 4C can reduce the level of interference between adjacent attenuators 44.

[0057] Although Figure 4A through Figure 4C show the electrical contacts 60 having substantially rectangular shapes, the electrical contacts 60 can have a variety

of different shapes. For instance, the electrical contacts 60 can be contoured to match the contour of the light signal path in the separation region 42 as shown in Figure 4D. Figure 4D is a top view of a portion of a functional light distributor 18 having the focal point 40 of a light signal. The dashed line illustrates the path of the light signal through the functional light distributor 18. The first electrical contact 60A and the second electrical contact 60B are positioned on opposing sides of the light signal path and have a shape that is complementary to the shape of the light signal path. Increasing the length of the electrical contacts 60 provides an increased level of attenuation. Matching the contour of the electrical contacts 60 to the light signal path can increase the attenuation efficiency.

[0058] Although Figure 4D illustrates the electrical contacts 60 as having a straight contour, the electrical contacts 60 can have a curved contour as illustrated in Figure 4E. A suitable curved contour includes, but is not limited to, a portion of a Gaussian profile. Further, the width of the electrical contacts 60 need not be constant along the length of the electrical contacts 60 as illustrated in Figure 4F.

[0059] Figure 5A and Figure 5B illustrate another embodiment of an attenuator 44 suitable for use with an equalizer 10 constructed as shown in Figure 3A through Figure 3C. Figure 5A is a top view of a portion of a functional light distributor 18 having a plurality of attenuators 44. Figure 5B is a cross section of the functional light distributor 18 shown in Figure 5A.

[0060] The attenuator 44 includes a first electrical contact 60A and a second electrical contact 60B positioned on opposing sides of the optical component 50. Suitable metals for the electrical contacts 60 include, but are not limited to, Ni, Cr, Ti, Tungsten, Au, Ct, Pt, Al and/or their silicides. The electrical contacts 60 can be formed to a thickness greater than .1 μm, .5 μm, 1 μm, 1.5 μm or 2 μm. Electrical conductors such as wires can optionally be connected to the electrical contacts 60 to provide electrical communication between the electronics and the electrical contacts 60.

[0061] A doped region 64 is formed adjacent to each of the electrical contacts 60. The doped regions 64 can be N-type material or P-type material. When one doped region 64 is an N-type material, the other doped region 64 is a P-type material. For

instance, the doped region 64 adjacent to the first electrical contact 60A can be a P type material while the material adjacent to the second electrical contact 60B can be an N type material. In some instances, the regions of N type material and/or P type material are formed to a concentration of 10^(17-21) /cm^3 at a thickness of less than 6 μm, 4 μm, 2 μm, 1 μm or .5 μm.

[0062] During operation of the attenuator 44, a potential is applied between the electrical contacts 60. The potential causes the index of refraction of the first light transmitting medium 52 positioned between the electrical contacts 60 to change as shown by the lines labeled A in Figure 5B. When the potential on the electrical contact adjacent to the P-type material is less than the potential element on the electrical contact adjacent to the N-type material, a current flows through the light transmitting medium 52 and the index of refraction decreases. The drop in the index of refraction causes a portion of a light signal traveling through the light signal carrying region 58 affected by the attenuator 44 to be diverted from the light signal carrying region 58. Optical absorption can also occur as is associated with silicon.

[0063] Although Figure 5A and Figure 5B show the electrical contacts 60 having substantially rectangular shapes, the electrical contacts 60 can have a variety of different shapes. For instance, the electrical contacts 60 can be contoured to match the contour of the light signal in the separation region 42 as shown in Figure 5C. Figure 5C is a top view of a portion of a functional light distributor 18 having the focal point 40 of a light signal. The dashed line illustrates the path of the light signal through the functional light distributor 18. The first electrical contact 60A has a shape that is complementary to the shape of the light signal path. Although not shown, the second electrical contact 60B can also have a shape that is complementary to the shape of the light signal path or can have shape that is different from the first electrical contact. Increasing the length of the electrical contacts 60 provides an increased level of attenuation. Matching the contour of the electrical contacts 60 to the light signal path can increase the attenuation efficiency.

[0064] Although Figure 4D illustrates the electrical contacts 60 as having a straight contour, the electrical contacts can have a curved contour as illustrated in Figure 4E. A suitable curved contour includes, but is not limited to, a portion of a Gaussian profile.

[0065] The arrangement of the attenuator 44 on the functional light distributor 18 can affect the attenuation efficiency associated with an attenuator 44. Increasing the efficiency of an attenuator 44 increases the portion of a light signal that is attenuated per amount of power applied to the attenuator 44. The efficiency of the attenuators 44 illustrated in Figure 4A through Figure 5D increases as the proximity of the index of refraction change approaches the position of the focal point 40 of the light signal(s) to be attenuated. Accordingly, the attenuators 44 are most efficient when the electrical contacts 60 are positioned so as to change the index of refraction of the light transmitting medium 52 at the focal point 40 of the light signal(s) to be attenuated by attenuator 44. For instance, the electrical contacts 60 of an attenuator 44 can be arranged such that the focal point 40 of a light signal to be attenuated is positioned between the electrical contacts 60.

[0066] The number of light signals attenuated by an attenuator 44 according to Figure 4A through Figure 5B is controlled by the location of the change in the index of refraction. For instance, an attenuator 44 can be configured to attenuate a single light signal when the electrical contacts 60 are positioned such that the change in the index of refraction can be limited to the path of the light signal to be attenuated. Further, the an attenuator 44 can be configured to attenuate a plurality of light signals when the electrical contacts 60 are positioned such that the change in the index of refraction occurs in the path of a plurality of light signals.

[0067] The base 54 can have a variety of suitable constructions. Figure 6A and Figure 6B illustrate a base 54 having a light barrier 70 positioned over a substrate 72. Figure 6A is a cross section of a waveguide and Figure 6B is a cross section of the functional light distributor 18. The light barrier 70 is selected to reflect light signals from the light signal carrying region 58 back into the light signal carrying region 58. A suitable material for the substrate 72 and light transmitting medium 52 includes, but is not limited to, silicon. A suitable light barrier 70 includes, but is not limited to, silica.

[0068] A silicon on insulator wafer can be employed to fabricate an equalizer 10 according to Figure 6A and Figure 6B. A silicon on insulator wafer typically includes a layer of silica positioned between a lower silicon layer and an upper silicon layer. The lower silicon layer serves as the substrate 72; the silica serves as the light

barrier 70; and the upper silicon layer serves as the light transmitting medium 52. The upper silicon layer can be masked and etched so as to form the ridge 56 in the upper silicon layer. The doped regions 64 can be formed at the desired locations using techniques such as impurity diffusion or masking and implantation. The electrical contacts 60 are formed over the doped regions 64. Mask and etch techniques can optionally be employed to form grooves at the desired locations in the light transmitting medium.

[0069] Figure 6C and Figure 6D illustrate another embodiment of a suitable base 54. Figure 6C is a cross section of a waveguide and Figure 6D is a cross section of the functional light distributor 18. The base 54 includes a substrate 72 having a pocket 76. The ridge 56 is positioned over the pocket 76. The pocket 76 contains a material configured to reflect a light signal from the light signal carrying region 58 back into the light signal carrying region 58. Suitable materials for the substrate 72 include but are not limited to, silicon. Suitable materials for containing in the pocket 76 include, but are not limited to, gasses such as air.

[0070] The substrate 72 can be selected such that light can be drained from the light transmitting medium 52 into the substrate 72 as illustrated by the arrow labeled A. As a result, portions of a light signal driven out of the light signal carrying region 58 by attenuation are drained away from the light signal carrying regions 58. Because the attenuated light signals are drained away from the light signal carrying regions 58, the attenuated light signals do not act as source of cross talk by entering into other light signal carrying regions 58. A suitable method of achieving the drain effect is to select the substrate 72 so as to have an index of refraction greater than or equal to the index of refraction of the light transmitting medium 52. This selection of materials reduces reflection that occurs at the intersection of the substrate 72 and the light transmitting medium 52. In some instances, the substrate 72 and the light transmitting medium 52 are the same material.

[0071] The entire functional light distributor 18 can be constructed with the base 54 construction illustrated in Figure 6D. Figure 6E and Figure 6F illustrate an alternative construction for the portion of the base 54 associated with the functional light distributor 18. Figure 6E is a top view of a portion of an optical component 50 having a functional light distributor 18. The dashed line illustrates the location of the

perimeter of the pocket 76. Figure 6F is a cross section of the functional light distributor 18 shown in Figure 6E taken at the line labeled A.

[0072] Although grooves 59 are not shown in the optical component illustrated in Figure 6E and Figure 6F, the addition of grooves 59 between adjacent attenuators 44 can serve to drive the attenuated portions of the light signal into the base 54.

[0073] The pocket 76 extends under some regions of the functional light distributor 18 while not extending under other regions of the functional light distributor 18. The pocket 76 is not positioned under a portion of the regions of the light transmitting medium 52 where the light signals do not travel. For instance, the light signals do not travel between adjacent attenuators 44 as illustrated in more detail in Figure 1B. The pocket 76 is not formed under the regions of the light transmitting medium adjacent to the attenuators. For instance, the pocket 76 is not positioned under the regions of the light transmitting medium 52 adjacent to the attenuators 44. As a result, the light transmitting medium 52 contacts the base 54 at regions of the light transmitting medium 52 located adjacent to the attenuator 54. The contact between the light transmitting medium 52 and the base 54 allows attenuated portions of a light signal 1to be drained out of the light transmitting medium 52 as illustrated by the arrows labeled A in Figure 6F. As a result, the attenuated portions of the light signal are less likely to be a source of cross talk.

[0074] Figure 7A through Figure 7E illustrate a method for fabricating an equalizer 10 according to Figure 6C and Figure 6D. Figure 7A is a cross section of a base 54. A suitable base 54 includes, but is not limited to, a silicon substrate 72. Although the base 54 is shown as being constructed from a single material, the base 54 can have a composite construction or can be constructed with two or more layers of material.

[0075] One or more pockets 76 are formed in the base 54 as illustrated in Figure 7B. The one or more pockets 76 can be formed with a mask and an etch or other techniques. As illustrated above, the pocket 76 is positioned under the ridge(s) 56 that define the waveguides, light distributors and the functional light distributor 18. Accordingly, the pocket 76 is formed so the ridge(s) 56 can be formed over the pocket 76 in the desired pattern.

[0076] A light transmitting medium 52 is formed over the base 54. The light transmitting medium 52 can be deposited or grown on the base 54. Alternatively, wafer bonding techniques can be employed to bond the light transmitting medium 52 of a wafer 78 to the base 54. A suitable wafer 78 includes, but is not limited to, a silicon on insulator wafer. As noted above, a silicon on insulator wafer typically includes a layer of silica 80 positioned between a lower silicon layer 82 and an upper silicon layer 84. The upper silicon layer 84 can be bonded to the base 54 as shown in Figure 7C. The lower silicon layer 82 and the layer of silica 80 can be removed to provide the optical component 50 precursor shown in Figure 7D. Additionally, a portion of the upper silicon layer 84 can be removed to provide the upper silicon layer 84 with the desired thickness of the light transmitting medium 52. Suitable methods for removing the lower silicon layer 82, the layer of silica 80 and the upper silicon layer 84 include, but are not limited to, etching, buffing, polishing, lapping, detachment through H implantation and subsequent annealing. The light transmitting medium 52 can be masked and etched so as to form the ridge 56 in the light transmitting medium 52 as shown in Figure 7E. The doped regions 64 can be formed at the desired locations using techniques such as impurity diffusion or masking and implantation. The electrical contacts 60 are formed over the doped regions 64. Mask and etch techniques can optionally be employed to form grooves at the desired locations in the light transmitting medium.

[0077] The methods described above include etching the light transmitting medium 52 so as to form a ridge 56 in the light transmitting medium 52. In order to reduce scattering of light signals, the etches should be selected so as to result in formation of smooth surfaces on the ridge 56. Suitable etches include, but are not limited to, the etches taught in U.S. Patent application serial number 09/845093; filed on April 27, 2001; entitled “Formation of an Optical Component Having Smooth Sidewalls” and U.S. Patent application serial number 09/690959; filed on October 16, 2000; entitled “Formation of a Vertical Smooth Surface on an Optical Component” each of which is incorporated herein in is entirety.

[0078] The optical components illustrated above are not necessarily proportional and the number of waveguides is not necessarily representative. For instance, the first array waveguide grating 16 is often shown with four first array waveguides 26

and the second array waveguide grating is often shown with four second array waveguides 28, however, array waveguide gratings often include a different number of array waveguides and can include as many as several tens or hundreds of array waveguides. Further, the equalizer 10 can include more than one input waveguide 14 and/or more than one output waveguide 24. Additionally, the equalizer 10 is shown with as few as three attenuators 44, however, the equalizer 10 can be employed in conjunction with tens or even hundreds of light signals. As a result, the equalizer 10 can include as many as tens to hundreds of attenuators 44.

[0079] Although the example attenuators disclosed above include a plurality of electrical contacts, a variety of other attenuators can be used in conjunction with the equalizer. Suitable attenuators can be constructed with other devices for tuning the index of refraction of the light transmitting medium. For instance, the attenuators can include a temperature control device such as a cooler. Reducing the temperature of the light transmitting medium causes the index of refraction of the light transmitting medium to drop. The index of refraction of a light transmitting medium often changes in response to application of a force to the light transmitting medium. As a result, the attenuators can apply a force to the light transmitting medium. A suitable device for application of a force to the light transmitting medium is a piezoelectric crystal. Further, the index of refraction of a light transmitting medium often changes in response to application of a magnetic field to the light transmitting medium. As a result, the attenuator can apply a tunable magnetic field to the light transmitting medium. A suitable device for application of a magnetic field to the light transmitting medium is a magnetic-optic crystal.

[0080] Although employing an attenuator so as to attenuate a plurality of light signals is shown in the context of an equalizer having a functional light distributor, one or more attenuators of a conventional equalizer can be adapted to attenuate a plurality of light signals. As a result, the conventional equalizer will require a reduced number of attenuators.

[0081] Although the optical component is disclosed in the context of optical components having ridge waveguides, the principles of the present invention can be applied to optical components having other waveguide types. Suitable waveguide

types include, but are not limited to, buried channel waveguides and strip waveguide.

[0082] Other embodiments, combinations and modifications of this invention will occur to those of ordinary skill in the art in view of these teachings. Therefore, this invention is to be limited only by the following claims, which include all such embodiments and modifications when viewed in conjunction with the above specification and accompanying drawings.